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ANALYTICAL TABLE OF CONTENTS.

INTRODUCTION

Cabbage Culture in Wisconsin 1
Extent of Present Thesis 3

LITERATURE RELATING TO THE DISEASE

In France

Prillieux and Delacroix, 1890 3
Prillieux, 1897 5
Delacroix and Maublanc, 1909 5

In Australia

McAlpine, 1901 6

In Holland

Ritzema Bos, 1906 9
Quanjer, 1907 17

In United States

Manns, 1911 22
Harter, 1912 27
Bailey, 1913 29

OCCURRENCE OF THE DISEASE IN WISCONSIN 29

CONTENTS

THE FUNGUS CAUSING BLACK-LEG

Morphology 35
Etiology 36

Cultural Characters

Preparation of Culture Media 41
Growth of the Fungus 46
Summary of Cultural Characters 53

SYMPTOMS AND FIELD RELATIONS OF THE DISEASE

In the Seed Bed

Symptoms 54

Means of Infection

In Young Seedlings 55
In Older Plants 56
Spread by Transplanting 59

In the Field

Early Summer Symptoms, Due to Seed Bed Infection, 60
In Late Summer, Methods of Late Infection . . 61
Individual and Varietal Resistance and Selection, 64
Practicability of Growing Cabbage Seed in Wisconsin , ... 67
Spread of Disease by Sale of Seedlings 70
Overwintering of the Fungus 70
Relation to Soil 71

CONTENTS

CONTROL AND PREVENTIVE MEASURES

Seed Disinfection 72
Inspection of Seedlings at Time of Transplanting 74
Rotation of Crops and Sanitary Measures 75
Control of Insects 75
Collection and Destruction of Cabbage Refuse . . 75
Selection and Breeding of Resistant Strains or Varieties 76

CONCLUSION

Unfinished Problems 77
Summary 78

BIBLIOGRAPHY 80

ILLUSTRATIONS 82

THE BLACK-LEG DISEASE OF CABBAGE.

INTRODUCTION.

Wisconsin has for several years been one of the leading cabbage producing states in the country. The growing of cabbages in a small way for the home and local markets by farmers and small truck growers is, of course, general, and probably occurs in every county of the state. In this case the cabbage is not the chief crop, and frequent rotation with other garden vegetables is practiced, so that as regards plant pathology this culture is not important, except in that it gives some opportunity for a wide and early dissemination of diseases.

Cabbages are grown in a more intensive way, however, in certain sections of the state. On the low, black lands along the shore of Lake Michigan, from Kenosha in the south to Green Bay in the north, winter cabbages are grown for storage purposes. This is the oldest branch of the industry in Wisconsin, and that in which this state excels. For twenty years the farmers near Racine have been growing cabbages on a large scale, storing them until late winter and then shipping them to the large cities, principally Chicago, St. Louis, Kansas City and Minneapolis. A good profit has been considered a certainty and frequently high prices received in early spring have brought

very large returns from a few acres. This fact has given some opportunity for speculation, with small chance for actual loss, and as a result the growers have planted large acreages year after year, often on the same soil, being loath to substitute for this crop others less profitable. Consequently, certain diseases have gained foothold and caused much loss, in some cases actually stopping all cabbage production in certain districts. Obviously the control of these pests is very desirable, and is imperative to the further culture of the crop in some sections, so from an economic standpoint the study of cabbage diseases is amply justified.

In more recent years another market for cabbages has developed. Kraut factories have been established at several points widely scattered over the state, at La Crosse, Green Bay, Racine and other places. Within a radius of several miles around each of these factories cabbages are raised more or less extensively, and here also have entered destructive diseases, causing much loss to the growers. In the neighborhood of Onalaska and La Crosse, where cabbages are produced for the Onalaska Pickle and Canning Company, the so-called "black-leg" of cabbage has for several years been an active cause of loss, and in some fields has destroyed the entire crop.

In the spring of 1911 this disease was first brought to the attention of the Department of Plant Pathology of the Wisconsin Experiment Station, and since that time its development has been followed. For one year, i. e., since the spring of 1912, the writer has been working upon this disease and the fungus causing it. Several trips were made to Onalaska to observe the malady in the seed bed and field; trips were made to widely separated parts of the state to ascertain how prevalent the trouble was in other sections; diseased plants were grown in the pathological garden and in the greenhouse of the experiment station and some inoculation experiments performed; the microscopic and cultural characteristics of the fungus were observed in the laboratory; and the previous literature on the subject was reviewed. The work is still very incomplete and the present paper is in the nature of a report of progress on these experiments and observations, together with a review of the literature.

LITERATURE RELATING TO THE DISEASE.

In France.

The first record of the occurrence of this cabbage malady was made in France by Prillieux and Delacroix (1890:114). Their description, translated from the French, is as follows:

" One of our correspondents has sent us from the school of agriculture at Pétré, near Luçon (Vendée), stems of marrow cabbage presenting spots which become more and more confluent as the root is approached. These spots are brown at the periphery and paler in the center. In them may be seen the numerous pycnidia of Phoma Brassicae, depressed, oval, the short necks perforating the epidermis of the stem.

" The spot observed on the stem is the starting point of a disorganization of the elements of the stem, which to the very center assumes a dark brown color, indicative of entire destruction.

" In the superficial region the cells of the cortical parenchyma appear under the microscope dissociated, deformed, with a brownish, coagulated content, or, indeed, their walls are disintegrated and broken down and all the cellular contents have disappeared.

" The plants attacked by this parasite decline rapidly; the leaves wither and soon lose their edible qualities. This disease causes a certain damage to the cultivators of this country, where the marrow cabbage is cultivated on a large scale for the feeding of animals.

" It is certain that the only method to arrest the invasion of the parasite is the destruction and burning of the infected stumps. "

Two figures are given, one representing the spores and the other a section of the pycnidium. These figures are fairly accurate, but are not very carefully drawn. The marrow cabbage, "chou moellier", mentioned by Prillieux and Delacroix is a large, fleshy fodder plant somewhat resembling kale. It is almost unknown in the United States, but has been tested at the Western Washington station and departed upon by W. H. Lawrence (1910:5).

Prillieux (1897:295) in his " Maladies des Plantes Agricoles ", gives substantially the above note, with the additional information that:

" The pycnidia contain enormous quantities of very small, hyaline spores, cylindrical, straight, rounded at both ends, not more than 3-4μ long by 1.5-2μ in diameter. . . . . . . The perithecial form corresponding to Phoma Brassicae is not known. "

The figures of the earlier book are reproduced, and one crude drawing is added.

Delacroix and Maublanc (1909:384) in their book on parasitic diseases of cultivated plants, again mention the disease, but add nothing new except to give the name Phoma oleracea Sacc. as a synonym of the name, Phoma Brassicae Thuem., which they had previously applied to the fungus.

The Disease in Australia.

The disease was reported in Australia by D. McAlpine. (1901). He states that it was first brought to his notice in 1897, in October, when he received some specimens of diseased cauliflowers found in Auburn, South Australia, where the loss was from 25 to 50 per cent. The stems were attacked and the roots had been rotted off; the affected parts below the surface of the ground showed numerous small black pycnidia. In another district, near Brighton, the loss from this trouble was even more severe, being estimated at £5,000; here it also attacked cabbages to a slight extent, though cauliflowers appeared to be much more easily susceptible. As to host plants he says:

" The disease causes the most injurious effects when upon the roots and stems of cauliflowers and cabbages, but it is not uncommon to find it upon the leaves of these plants in midsummer, as well as upon those of turnip and rape."

Speaking of the symptoms of the malady, he continues:

" A plant attacked by this disease is easily recognized, the leaves have a sickly withered look, the stem is shrivelled, and the roots become brown and rotten. If a plant is pulled up the underground parts show numerous little black points visible to the naked eye, which constitute the fructification of the fungus. Even in the seed beds

plants attacked may be recognized by their sickly appearance. . . . . . It is in the roots particularly that the worst effects are produced. The tissue decays in large patches, which become confluent, and soon spread right round. The interior is also invaded, the woody fibre becomes blackened, and the plant soon dies. "

McAlpine accepts Phoma Brassicae Thuem. as the name of the causal fungus, probably upon the authority of Prillieux, whose description of the disease he had evidently seen. He mentions no authority and gives no reasons for his use of the name, merely stating:

" The disease is undoubtedly produced by the fungus [Phoma brassicae Thuem.], and the numerous often densely crowded perithecia or spore cases at the surface are the fructifications of the fungus. "

He says, "There is every reason to believe that this fungus can only gain access to the young plant, as the disease is observed even in the seed bed. "

The following suggestions are given for control or prevention of the disease:

" 1. All diseased plants should be removed and burnt as soon as the disease is detected.

2. Different varieties resist the disease differently, so seed should be selected from those varieties which heve been most resistant and less easily succombed to the disease.

3. No refuse from diseased fields should be added to the manure heap, since the disease is thereby spread.

4. The seed beds should be treated, preparatory to sowing, with a fungicide such as sulphate of copper. In dealing with a serious fungus disease of the tobacco plant I found that treatment of the seed bed on the same day as the seed was sown was very effectual.A strong solution of bluestone was used, at the rate of 4 lbs. to 50 gallons of water;and Bordeaux mixture at the rate of 2 lbs. bluestone and 2 lbs. quicklime to 10 gallons of water has likewise been tried."

McAlpine has included in the bulletin a colored plate of a cabbage stump attacked by black-leg, and several photomicrographs showing pycnidia of the fungus in various stages of development. He has also added the description of a large garbage incinerator for the destruction of cabbage refuse on a large scale.

It is evident that McAlpine did not make a very critical study of the disease nor of the fungus causing it, but his popular bulletin shows the result of much careful observation, and the control measures recommended are sensible and practical.

In Holland.

Prof. J. Ritzema Bos of Wageningen, Holland, published a report of work upon the black-leg disease (1906:257). He makes the interesting observation that in Holland the malady takes two forms; that is, what were at first thought to be two distinct diseases he finds to be caused by the same organism. The first is what he calls "Fallsucht" or "Falling-sickness", and is evidently the same as our "black-leg"; the second is a rot which occurs in storage, and to which he gives the name "Krebsstrünke" or "Stem-camcer". Most of his field work was done in the region of Langendyk, North Holland, where he had several experimental fields under observation. Langendyk is, he says, the center of the cabbage industry in the Netherlands; here cabbages are sometimes grown on the same land for twenty successive years.

The "falling-sickness", or, as we shall call it, the"black-leg", first came to his notice in 1902 near Langendyk, but in the following years it spread into several parts of the cabbage district of North Holland. Following is a translation from the German of what he says regarding symptoms of the disease:

" The chief symptom of this disease consists in a decay of the tap-roots in a few and probably in most cases a very short distance from the surface of the ground. These

roots become rotten, in the course of which the more tender tissues finally disappear altogether, and only the more solid or woody parts remain. Very often the roots look as though they had been gnawed locally by insects, and become rotten and shrivelled later.

". . . . . . Where the tap-root becomes entirely rotten and shrivelled at one point new lateral roots often form at the base of the stem. If these side roots attain strong development the cabbage plant can support itself sufficiently to continue to exist; it forms a head, which, however, usually becomes much too heavy to be borne upright by the plant, whose tap-root is decayed, so that the plant finally topples over.

" It may also occur, however, that the lateral roots form freely and attain a vigorous development, so that the plant suffers relatively little through the dying of the tap-root, and the head attains to somewhat normal development, as a result of which nothing is to be observed of the disease above ground. "

In the spring of 1904, in response to complaints from the Langendyk cabbage growers as to the early appearance of black-leg on young cabbage plants, Ritzema Bos visited this cabbage district repeatedly and examined many young plants taken from various seed beds. On such diseased

seedlings, he says, the root near the base of the stem becomes discolored, grayish brown, and, according to the weather, decomposed by either a wet or a dry rot. The tap-root is always lost, and often the seedlings die, but lateral roots arise and frequently become so vigorous that the loss of the tap-root is not felt and the seedling is apparently suitable for transplanting. In still other cases the lesion seems to heal perfectly, and here again the infected seedling is transplanted.

By tracing the history of plants from certain diseased and unaffected seed beds it was found that the seedlings might become infected in the bed and carry the disease into the field, or, if healthy seedlings were planted into fields where the disease had been present previously they might become infected after transplanting.

Very young cabbage seedlings affected with black-leg can be recognized by the experienced grower by the more nearly vertical position of the leaves, those on normal plants becoming somewhat horizontal. Leaves of the diseased plants are also slightly paler in color, and the plants are smaller and less vigorous.

The variety most susceptible to attack by both black-leg and stump-cancer he finds to be the red cabbage; next comes the Wirsing, or Savoy cabbage; third the Danish head-cabbage; while the cauliflower is much less susceptible.

The opinion of many growers is that individuals with hard vascular bundles are more often attacked than those with more tender stems. Plants on heavy clay soil appear to be more resistant than those grown on lighter soil.

The stump-cancer, according to Ritzema Bos, cannot be recognized in the field before harvesting, but when the plant is cut the disease can usually be observed by careful scrutiny as a very small black stain in the woody ring of the stem. It is only in the winter, in the storage rooms, that it becomes plainly noticeable. First there originate in the stem indefinite discolored spots, at first faint and small, but spreading irregularly and becoming darker. After a time the discoloration extends into the leaves, first by way of the principal veins, where in a few spots, mostly nearly the axils of the leaves, the color becomes dark, almost black. In this stage the symptoms might possible be confused with those of black rot, caused by Bacterium campestre, but can be distinguished from it by the greater irregularity of the spots and the lack of uniformity in following the vascular system; the black-leg soon starts to spread through the whole leaf in any direction it chooses. The extent of the discoloration of the leaves increases rapidly during the spring, especially in a warm, moist atmosphere. The leaves are often severed from the stem by the decay, and drop off. The diseased spots finally take on a

whitish color from the cracking of the epidermis; at their margins may often be noticed a wooly, compact mycelium, while in the dead areas within may be found the pycnidia of the fungus, at first red, later brown, and finally turning black.

The brownish discoloration of the diseased spots is caused by the color of the cell walls when the cell contents have shrunk together. The tissues are thickly interlaced with a mycelium, partly inter- and partly intra-cellular, which branches abundantly within the cells. The mycelial threads are septate, variable in diameter up to 5 µ, and contain many highly refractive droplets, also varying in size. No organism other than this mycelium was found in the affected spots, and the fungus was found as far as the disease had reached, so Ritzema Bos concluded that this fungus is the cause of the disease.

Cultures of the fungus, he states further, develop rather rapidly on malt agar, and in a couple of weeks give rise to pycnidia similar to those found on the diseased cabbage tissues. On the cut stems of stored cabbages these pycnidia develop abundantly; on the leaves they are borne under the epidermis which, when mature, they rupture, and come to the surface. The pycnidia are oval, with a thick, pseudo-parenchymatous wall, and at maturity they develop in the middle of the upper side a nipple-shaped prolongation,

which soon flies open and liberates countless conidia in a rose-colored, serpent-like, slimy, twisting stream". The pycnidia vary in diameter from 0.20 to 0.35 mm., with a height of about 2/5 of the diameter. From the wall there extend into the interior very short, thick conidiophores, from the ends of which are cut off one-celled, oval conidia, usually clightly constricted in the middle, hyaline, with a highly refractive droplet in each end. The conidia are 5-5.5μ long and 2-2.2μ in diameter.

From the above characters Ritzema Bos decided that the fungus belongs to the genus Phoma Fries. Among the species of Phoma mentioned by Allescher and Saccardo there is only one whose description coincides with that of the fungus studied; that one is Phoma oleracea Sacc., so that name is assigned to the cause of stump-cancer.

No disease of cabbage has been described as being caused by Phoma oleracea Sacc. But the malady described by Prillieux and Delacroix as due to Phoma Brassicae Thuem. having many points of similarity, Prof. Ritzema Bos compares the diseases and fungi rather critically, and concludes:

" It appears to me that the relatively unimportant differences between the Phoma disease of the marrow cabbage and that of the head-cabbage of Langendyk may be easily explained by the differences between the varieties of cabbage concerned and the different conditions under which

the disease appears. "

Allescher states that Phoma oleracea Sacc. is erroneously called by Delacroix Phoma Brassicae Thuem. Since Allescher's description corresponds exactly with that of the fungus causing stump cancer, Ritzema Bos finally accepts for this fungus the name Phoma oleracea Sacc.

Returning now to the black-leg or "falling sickness", he reviews the symptoms of the disease, and mentions finding in and on the diseased tissues a mycelium similar to that found in stump-cancer. But not until 1904 did he see any fruiting bodies on such diseased plants; at that time they developed on some seedlings that he had kept in a moist chamber for about ten days. These fruiting bodies were found to coincide morphologically with those of the Phoma oleracea of stump-cancer; he later found the pycnidia repeatedly, and after a number of observations he concluded that the two diseases were caused by the same organism. To settle this point he obtained a pure culture of Phoma from conidia developed on a plant suffering from black-leg. He grew this on an agar medium containing cabbage stem decoction. When conidia formation had started he cut in two a couple of healthy heads of old cabbage, placed a little of the mycelium on the cut surfaces, tied the halves together again, and put them in a moist place. After a few days the typical stump-cancer appeared, and the pycnidia of Phoma

oleracea were produced in abundance. From this it seemed clear that the same fungus was the cause of the two diseases.

Since plants attacked by black-leg did not usually form marketable heads it was rather difficult to understand how stump-cancer could originate, but the explanation was given that very often the vigorous young seedlings attacked by Phoma apparently overgrow the fungus, the lesions heal, and the disease may be forced to remain in a dormant state during the vigorous growth of the host. But after the plant is mature and is put into storage in a resting condition an opportunity is given the fungus to spread, and the result is the typical stump-cancer.

Many farmers were of the opinion that the black-leg could be carried over by the seed, but after a number of tests Ritzema Bos concluded that this was not the case. However, he raises the question as to whether there may not be a hereditary predisposition to the disease. No experiments were performed to determine this.

He states that his experience has not shown that the return of cabbage refuse to the land as manure furthers the spread of the disease, and since this refuse was found to be an excellent fertilizer, he does not think it best to recommend the discontinuance of the custom.

The paper of Ritzema Bos is illustrated with several drawings and photographs showing the diseased cabbage leaves and stems and the fungus as it appears under the microscope.

The investigation of the mode of entrance of the fungus into the host tissues and of the relation of insects to the spread of the disease was left by Prof. Ritzema Bos to his assistant, H. M. Quanjer. Quanjer worked upon this problem during the seasons of 1905 and 1906, and reported (1907:258) upon his work in 1907, the year following the publication of the article of Ritzema Bos.

It soon occurred to Quanjer that the early symptoms of black-leg were very similar to those following injury of the roots by insects, and on this subject he says:

" Further observations taught me that in reality the first stage of "falling-sickness" is identical with the result of mechanical destruction of the roots, caused in most cases by Anthomyia brassicae Bouche, but occasionally by wire worms or other injurious insects. Later, Phoma oleracea may establish itself in the wounded parts and produce a complication which displays the typical, long-enduring falling-sickness, while the destiny of the merely mechanically injured plants is soon determined: either they recover by means of the formation of adventitious roots, or they quickly dry up. "

Continuing, he states that Ritzema Bos proved that Phoma oleracea is a direct pathogen for mature, harvested cabbage heads, and that germination tubes from spores placed on the leaf surfaces quickly penetrate through the stomata and produce infection; but that upon young, healthy plants the fungus is only a weak parasite. In his own experiments he was unable to inoculate vigorously growing plants except through wounds made by the cabbage fly or through similar injuries artificially made. Another series of experiments showed that even the wilting that followed transplanting presented a weakened condition which made possible the penetration of the fungus into the roots. Besides the cabbage maggot he found that other pests, such as flea-beetles, wire-worms, snails, and the larvae of a species of Baris, play lesser parts in the infection of the plants; probably all these pests carry the fungus from diseased to healthy plants, though this fact was proved only for the cabbage-flies. Man and animals also help to spread the disease, but it is not carried on the seed.

He found that the vessels of infected plants become filled with a hard, resistant brown gum, and concluded that the hardness of the core, which many growers believe to be a characteristic of the more susceptible cabbages, is a result of the disease, and has nothing to do with its cause.

By a large number of measurements he found considerable variation to occur in the size of the conidia of _Phoma oleracea_; this strengthens the belief expressed by Ritzema Bos that this fungus is identical with that described by Delacroix in France. As the result of inoculation experiments Quanjer states that the fungus "is pathogenic for cabbage and cauliflower plants that have stopped their vigorous growth, as well as for the roots and resting organs of other crucifers, as, for example, for the cut-off, mature roots of kohlrabi and horse-radish, but not for either the growing or the resting organs of the representatives of other families."

His field observations indicated that the weakest or least vigorous races of cabbage (usually connected with the development of the root system) were the ones most easily and frequently attacked by black-leg, and that herein lay the "hereditary susceptibility" suggested by Ritzema Bos; he therefore emphasizes the importance of the selection of vigorous individuals for the production of seed, and of placing a limit upon too close relationships in breeding.

Quanjer attempts to explain several difficult points by the application of his theory of the infection of vigorous plants only through insect wounds. To illustrate: he determined that _Phoma oleracea_ was only a weak parasite for young, vigorous plants, and yet there exists the

fact of the wholesale infection of seedlings in the seed beds. He explained this by saying that the seed beds were usually located near the storehouses, where the cabbage flies lived over winter in large numbers in the refuse, and in the early spring infested the seed beds, which, being on light soil and partly protected from the wind, afforded the most favorable conditions for the multiplication of the pests; with the insects in abundance, infection from Phoma was inevitable. Again, this would tend to explain the apparent greater resistance to black-leg of plants growing on heavy clay soil, since the cabbage flies prefer a light, sandy soil in which to deposit their eggs. This theory was also applied to the explanation of the fact that the leaving of cabbage refuse on the land in the form of manure did not increase the virulence of the disease, although the fungus was undoubtedly present in abundance in the old cabbage stumps. He says:

" That a distinctly injurious influence did not proceed from this custom was explained by the circumstance that that the fungus contained in the stumps was not able to attack the uninjured roots; some insect bite or similar injury must first take place. "

As to control of the black-leg Quanjer says:

" It is very evident that a natural means of resis-

tance against the falling-sickness is sought for in the breeding of races with strong root systems. "

But as a very natural conclusion to his article he says:

" The fight against falling-sickness has to be directed mainly toward a fight against the cabbage fly, and since Nature has not come to our assistance with an epidemic disease of this parasite we must fight our own way through, and we will in that way be directed toward a means of prevention. "

For the control of the cabbage fly he recommends inspection and washing of the seedlings at the time of transplanting, and their protection in the field by the placing of a handful of slaked lime around each stem.

Although the theory and explanations of Quanjer are ingenious and rather well worked out, although they appear somewhat plausible and are evidently the result of much thought and observation, yet it seems to the writer that he assumed a too extremely entomological point of view. There is undoubtedly much truth in what he says, but his sweeping deductions should be applied with moderation, His statements have not all been proved experimentally; his results need corroboration.

In United States.

The next publication upon the black-leg of cabnage came from the United States, from the Ohio Experiment Station, when T. F. Manns (1911:276) gave in a bulletin the results of his one year's acquaintance with the disease. After outlining the extent and history of cabbage production in Ohio he gives recommendations as to general cultural methods and means for the prevention of the spread of diseases. He very briefly reviews the literature pertaining to black-leg. He mentions that Germany has been subject to the trouble for some time, but gives no authority for the statement.

The disease has been reported from seven counties in Ohio, in some places causing total losses. Although having apparently been active in the state for five or six years, it did not come to the attention of members of the experiment station until the spring of 1910, when " the seed beds showed considerable infection previous to the time of transplanting. " He describes the appearance of the malady as follows:

:" The preliminary symptom is that of white, sunken, elongated oval areas on the stem [of the seedling], usually below the point of leaf attachment. There appear early in these lesions, small black bodies equally distributed over

the affected areas; these black specks are the fruiting bodies (pycnidia) of the fungus. . . . . . These infested areas soon become confluent, the tissues die and break open, following which bacterial and fungus contaminations set in. In the preliminary attack, the disease causes no foliage change through which the trouble may be distinguished, unless lesions are formed on the leaves directly, which seldom occurs in the seed bed. Seedlings about to collapse with the disease take on a bluish red color of the foliage. "

He continues by stating that affected plants die in all stages of their growth, but that the greatest loss occurs when they are one-half to two-thirds grown, when the symptoms are very characteristic.

" The foliage . . . . . . takes on at the margins a mottled, metallic, bluish red color. The lower, outer leaves show evidence of wilt. Total collapse may take place in twenty-four to forty-eight hours. Examination of the stems . . . . . . reveals large, sunken lesions one-half to two-thirds the distance through the stem or sometimes showing a sunken collar rot, so far destroying the stem as to allow the top to break off easily. . . . . . If rains are favorable, the infested plants may set root again from above the place of injury. These adventitious roots are seldom sufficient to mature a marketable product. "

In regard to the relation of insects to the entrance and spread of Phoma Manns says:

" The observations made by the writer in the seed beds and fields, together with experiments upon seedlings of the varieties 'All Season' and 'Market Garden', convince him that the importance of insect association, as noted by Bos and Quanjer in Holland, does not apparently hold true for the disease in our own districts. In fact, the disease was produced in abundance in seedlings by placing washings from diseased material with the seed at time of planting. Many of the plantlets died before the third leaf was formed. No association whatever of maggots was found with this early seedling infection. "

" Wherever Phoma 'foot rot' is found associated with the maggot work, it simply means that the insect has made it easier for the fungus to get a foothold. "

" There is little doubt that insects, viz., the cabbage maggot, the cabbage curculio and wireworms may be, and quite generally are, instrumental to some degree in distributing and facilitating the fungus in its work on the cabbage. On the other hand, the evidence is sufficient to show that the fungus is a direct pathogen on seedlings and susceptible plants. Under, warm, damp storage conditions the fungus spreads rapidly. In shipping by express a number

of infected plants from Clyde, Ohio, in which the shipment was five days in transit, the disease spread rapidly over the plants, fruiting abundantly on the partially wilted leaves. "

Manns says that the black-leg seems to make its greatest progress on the black- soils, but also occurs on the lighter soils. Moisture appears to be more favorable than soil texture as a factor influencing the spread of the disease.

He accepts the name Phoma oleracea Sacc. for the fungus causing the trouble.

" The arrangement of the fruiting bodies (pycnidia), their size, 1/4 to 1/3 millimeter in diameter, together with the spore measurements (4.5 to 5. m.m.m. by 1.7 to 2. m.m.m.), and other characteristics, all indicate the organism to be the above named fungus. "

In a footnote he adds, after quoting Saccardo's descriptions of Phoma Brassicae Thuem. and Phoma oleraceaSacc.:

" Prillieux's illustration of the pycnidium shows the pycnidia to be arranged singly and submerged, similar to Phoma oleracea.

" McAlpine, on the other hand, in his plate VII (p. 276), shows photo-micrographs in which the pycnidia are superficial and densely aggregated. These distinctions would seem to justify McAlpine in designating the organism

as Phoma Brassicae. "

Regarding control measures, Manns says:

" The writer would recommend treating the seedbeds, immediately after planting, with a Bordeaux mixture (4-4-50 formula) at the rate of one gallon per ten square feet. Use a sprinkling pot, or a foot spray pump. The bed should again be sprayed, using a spray pump, two weeks before transplanting and again just before transplanting. These treatments will keep the disease down in the seedbed, and prevent distribution of the disease during transplanting. "

As preventive measures he recommends control of insects, destruction of refuse, and location of seedbeds on uninfected soil, combined with the practice of proper rotation of crops.

The bulletin contains several photographs showing the characteristic lesions of the disease, and one showing a plate culture of the fungus. The drawings of pycnidia and spores are somewhat diagrammatic and are not carefully done. It must be considered, of course, that the paper is intended to be rather popular in character. Its chief value lies in its fairly sccurate description of the symptoms of the disease as it appears under the climatic, soil and cultural conditions of this country.

The Disease in Other States.

L. L. Harter (1912:21) of the United States Department of Agriculture, has prepared and published a popular bulletin dealing with cabbage diseases; in this a few pages are devoted to a discussion of Phoma.He first gives the known distribution of the fungus, saying that in the United States it has been reported from Ohio, Michigan, Iowa, Virginia, Wisconsin and New York upon cabbage, and from Louisiana upon cauliflower. The greatest destruction occurred in the trucking sections of tidewater Virginia, where as much as seventy-five per cent. of the crop was destroyed in some fields. He says that he has not personally observed the disease upon cauliflower in the field, but has easily produced it in the greenhouse by artificial inoculation.

Harter mentions the fact that one of the chief symptoms of the disease is a purplish coloration which develops in the foliage before the plant dies, and persists until its death. "Wilting of the whole plant is very characteristic of black-leg of cabbage. The leaves, instead of falling off, adhere to the stem and droop down as though suffering for water. "

" Black-leg is caused by a fungus (Phoma oleracea Sacc.).

" Infection takes place on the stem near the ground, probably in wounds made by insects, and spreads from that point around the stem, down into the roots, and up into the leaves. Leaf infections also occur at the margins, generally at the ends of the large veins. The fruiting bodies of the fungus appear as black specks (pycnidia) in the lesions and abrasions. In the pycnidia are formed myriads of microscopic one-celled spores which upon oozing out are exposed to the winds, insects, and other foreign agencies, by which means they are probably carried to other plants. Wet weather is favorable for the spread of the disease, the greatest loss being occasioned during a wet season. "

Harter shows two photographs, one of the lesions and pycnidia of Phoma upon a cabbage leaf, the other, a field in which most of the plants had been killed by the disease.

Regarding measures for prevention and control, besides those already recommended by other authors, Harter states that his own experience has shown that steam sterilization of the soil for one hour at a temperature of 212° F. will prevent the disease in the seed bed. In addition, he advises disinfection of the seed bed with formaldehyde, by immersion for fifteen minutes in a solution made up of

Formaldehyde (40 per cent.)	1/4 pint,
Water	7 gallons.

The seed should then be dipped in water and spread out to dry.

Since the publication of Harter's bulletin the black-leg has been reported in Oregon by F. D. Bailey (1913:270), who says that it is quite widespread in that state.

Occurrence in Wisconsin.

In Wisconsin the black-leg of cabbage was first observed in the spring of 1911 in the fields near Onalaska, La Crosse County. It had evidently been present in the neighborhood for some time previous to this, for it had already gained a considerable start and was causing much damage in certain fields. Professor L. R. Jones, of the Wisconsin Experiment Station, visited Onalaska and discovered the disease in the seed bed and the field, and gave some attention to it during the summer and autumn. He also recommended measures for prevention and control. In late June, 1912, the disease was again found in the seed bed, and field by Professor Jones and soon afterward by the writer. Following this, during the summer and autumn, the writer made several trips to Onalaska in order to learn the history of the disease and to watch its development throughout the season. It was found that for six or seven years cabbages had been raised in this vicinity to supply to the kraut factory at Onalaska. Though grown on a decided-

ly commercial scale, they did not form one of the principal farm crops in the region; relatively little attention was paid to method of culture and as a result the disease had, after gaining a foothold, spread into nearly all the fields within a radius of several miles.

In some fields, probably where better cultural methods and proper rotation had been practiced, only a few plants were, during 1912, affected with the malady. In others, varying degrees of damage had occurred, and in one field of several acres not a single head had been harvested, all having been ruined by the black-leg.

Later in the autumn the disease was found in a private garden in the city of Madison and was also discovered in abundance in a truck garden in Dane County, abour three miles west of Madison.

Early in September the malady was discovered by Professor Jones, in one field on the farm of H. P. Tennessen's Sons, at Birch Road, north of Kenosha, in Kenosha County. Here it was associated with "Yellows", the Fusarium disease. On September sixteenth the writer visited a number of farms in the vicinity of Birch Road, which is in the heart of the oldest cabbage growing district in the state. Black-leg was found in several fields, and was especially destructive in a small field of red cabbage on the farm

of Mr. Witcheber. The trouble was also present in the fields of Mr. W. E. Thompson.

By this time the suspicion had developed that the disease was much more widely disseminated than had been supposed. Since complaints of cabbage troubles had come to the station from several points in the state a trip was made on September nineteenth to the cabbage sections near Green Bay and westward, to determine the extent of this and other diseases. In this vicinity the cabbages are grown partly for kraut and partly for storage purposes. At Green Bay they have been raised commercially for about twenty years, but near the smaller towns west and north from this city the industry is of quite recent origin. Throughout this whole region cabbages as well as other crops had suffered greatly during the summer and early fall from excessive moisture, often whole fields being drowned, and few fields were entirely exempt from loss from this factor. The weakened, unhealthy condition of the plants made the search for specific diseases difficult in many cases, but it also gave an unusual opportunity for parasitic diseases to become established and to spread, if there were any sources of infection in the neighborhood. It was discovered that cabbage plants, nearly killed by excessive water after they have become almost mature under more favorable conditions, exhibit symptoms very similar

to those of black-leg; the leaves assume a purplish color, the roots are very often rotted away entirely (though by a soft rot), and the plants collapse and topple over.

At Green Bay much damage was found to be due to the bacterial black rot, caused by Bacterium campestre (Pammel) Erw.F.Smith; a few plants were found affected with " Yellows "; and in some fields considerable numbers of plants had been attacked by the Phoma or black-leg.

At Shiocton, a village thirty-two miles west from Green Bay, the cabbage industry is comparatively new but is of surprising magnitude. The writer was told that in the fall of 1911 about 800 carloads of cabbage (approximately 12,000 tons) were shipped from this station, and that enough cabbage had been planted in 1912 to produce, under favorable conditions, 2,600 carloads. The writer estimated that very nearly two thousand acres had been planted to cabbage within a few miles of the village, However, mainly as the result of the high water, very few cabbages were harvested, probably little over one-fourth of the total acreage planted, so the loss was enormous. It is the custom at Shiocton to ship in the fall as many cabbages as possible, and to store the rest for the winter. Nearly every farmer stores a few, and there are three large commercial storehouses in the village.

South of Shiocton and east towards the village of Black Creek the land is somewhat higher than elsewhere, and here many good fields ofcabbage were to be seen. The best field seen was twenty acres in extent, on rather high land; the plants were in excellent condition and had formed good heads; parasitic diseases were causing practically no damage. Although the writer inspected the field rather carefully he was able to find only three plants affected with black-leg. Indications were that this field would produce between fifteen and twenty tons of marketable cabbage to the acre. In most fields, however, the prospects were anything but encouraging, and northward and west toward New London the crops were entirely destroyed. In many fields, even the very wet ones, the ground was found to be thoroughly infested with "white grubs", which did considerable injury to the cabbage roots. Wire-worms were also found to be abundant.

At New London it was found that all cabbages had been destroyed by the high water.

At Appleton Junction three fields were inspected hrrriedly, and a few plants were found affected with black-leg.

Out of all the fields, of a few acres or more in extent, visited by the writer during the entire summer and fall, less than a half dozen were found that did not

contain any plants attacked by Phoma. The disease was seen in the field in the counties of Dane, Brown, Kenosha, La Crosse, Outagamie and Racine. Later a specimen of black-leg was sent to the experiment station from St. Croix County, where the farmers are beginning to grow cabbages on a commercial scale. From these observations it appears probable that the disease is present to some degree in every large cabbage-producing section, and only awaits conditions favorable for its growth, such as successive planting of the land to cabbage, to spread rapidly and bring about such loss as has been suffered at Onalaska. With this idea in mind it seems surprising that black-leg has not already caused more serious injury in all the older cabbage-producing regions of the state. This may be partly explained by the fact that in these older sections the growers have been careful, experienced gardeners, who have watched the development of their crops intelligently and have followed rational methods of sanitation and culture.

THE FUNGUS CAUSING BLACK-LEG.

Morphology.

The fungus *Phoma oleracea* Sacc., which is the cause of black-leg of cabbage, belongs to the family Sphaerioideaceae of the imperfect fungi. Its mycelium is much branched, at first sparingly septate, hyaline, containing many highly refractive droplets; soon it becomes somewhat yellowish brown and abundantly septate. The threads are small and irregular, varying in diameter from 2 to about 6 . In the tissues of the host the mycelium is both inter- and intra-cellular, often sending out many short branches within the host cells.

The pycnidia are produced scatteringly near the surface of the tissue but beneath the epidermis. They are rather thick-walled, their walls being composed of a mass of short, closely packed mycelial threads. The spores are said by Ritzema Bos to be produced on the ends of very short, thick conidiophores, though this has not been observed as yet by the writer. The entire interior of the pycnidium becomes filled with a mass of detached spores. Before maturity the pycnidium ruptures the epidermis of the host tissue and comes to the surface; it is globose, somewhat depressed above, and develops in the center of the top a short ostiole from which the spores issue when mature in a solid, compact stream which soon breaks apart, and the

spores are scattered. Mature pycnidia often reach a diameter of 0.3 mm., but many are much smaller.

The individual spores are hyaline, one-celled, cylindrical, rounded at both ends, usually slightly constricted in the middle, and conspicuously bi-guttulate; most commonly they are 4.5 to 6.μ long by 1.5 to 2.μ wide, but occasionally they are found, especially in artificial cultures, but also on the host, only 3.5 to 4.μ in length. This variation in size would seem to indicate that this character, which is given by Saccardo as one of the chief differences between Phoma oleracea Sacc. and Phoma brassicae Thuem., is not reliable as a means of distinguishing the two species. The characters of our fungus coincide very closely with those given by Ritzema Bos for the fungus causing "Fallsucht" and "Krebsstrünke", and also with those of the fungus named by Saccardo (1882:91) Phoma oleracea. All the other species of Phoma listed by Saccardo in his "Sylloge Fungorum" (3:119,135) do not coincide so closely in morphological characters with the fungus causing black-leg of cabbage.

Following is the original description of Phoma oleracea as given by Saccardo (1882:91).

" 774. Phoma oleracea Sacc. Perithecis sparsis, globoso-depressis, papillulatis, 1/4 - 1/3 mill. d., initio

velatis, spermatiis, oblongo-subcylindraceis, medio quandoque subconstrictis, utrinque obtusiusculis, 5-6 x 2, 2-guttulatis, hyalinis.--In caulibus *Brassicae oleraceae* L.— Affinis, sed non identica, cum *Ph. herbarum* West., a qua spermatiis angustioribus differt. "

In English this description would read as follows:

" Pycnidia scattered, globose-depressed, papipiolate, 1/4 - 1/3 mm. in diameter, covered at first; spores oblong-subcylindrical, sometimes cubconstricted in the middle, somewhat obtuse at each end, 5-6 by 2μ, bi-guttulate, hyaline. Occurs in stems of *Brassica oleracea* in France. Similar to, but not identical with, *Ph. herbarum* West., from which it differs in narrower sporules. "

In listing this species in his Sylloge Fungorum, Saccardo adds (*3*:135):

" Possesses the following varieties: Var. *Antirrhini*: spores 4-5 x 1.5-2μ. Var. *Urticeae*: spores 5-6 x 2μ. Var. *Scrophularieae:* spores 5 x 2μ. Var. *Dipsaceae*: spores 5 x 1.5μ. Var. *Solidagini*: 5-6 x 1 1/4μ, slightly curved. Var. *Helianthi tuberosi*: spores 5 x 2μ, straight. "

The species with which the present fungus has been confused is that of von Thuemen (1880:189); his description follows:

" Aposphaeria Brassicae Thuem. nov. spec. Peritheciis majusculis, dense aggregatis, saepe confluentibus, hemisphaericis, plicatis, e obscure fusco-nigris, superficialibus; sporis numerosis, cylindraceis, rectis, utrinque rotundatis, continuis, anucleatis, hyalinis, 3-4 mm. long, 1.5-2 mm. crass.--An Gibberae Saubinetii Mntg. conditio? In Brassicae oleraceae caulibus putridus.--Supl. No.798. "

The English translation of the description is as follows:

" Pycnidia large, densely aggregated, sometimes confluent, hemispherical, plicate, superficial, externally dark reddish black; spores numerous, cylindrical, straight, rounded at each end, non-septate, enucleate, hyaline, 3-4μ long, 1.5-2μ in diameter.--In rotten stems of Brassica oleracea.--Supl. No. 798. "

It may be seen that the pycnidia of our fungus are not usually densely aggregated, plicate, nor superficial, and that the spores are bi-guttulate and are longer than those described by von Thuemen. However, variations have been found by the writer which would be included under all these terms, so there is a question as to whether von Thuemen's description was of a distinct species or whether the differences may be explained by the differences in environment and host plants involved. At least until it has been proved that this is the case the name Phoma oleracea Sacc. should be accepted for the fungus in question. It should be noted

that when Saccardo listed von Thuemen's description in his Sylloge Fungorum (3:119) he changed the genus, giving it as *Phoma brassicae* Thuem.

Notice should be taken of the species described by Desmaziere, in French (1849:281). The translation follows:

" *Phoma Lingam* Desm.-*Sphaeria Lingam* Tode, Fung. Meckl. --Alb. & Schw., Consp.--Pers., Syn. fung.--Fr., Syst. Myc.--Duby, Bot.--Wallr., Comp. fl. germ.----- *Phoma Lingam*, not very well understood, is found in spring on the wilted stems of *Brassicae oleraceae rubra*; few species of the genus are known to be so polymorphic; its perithecia vary greatly in size; they are rounded, oval or deformed, convex and without brim or collapsing and concave with a thick rim. Sometimes the ostiole is lacking or papiliolate; sometimes elongating into a minute, cylindrical and very delicate beak. Surface of perithecium plain, or marked by a furrow in figure of a *Hysterium*, or frequently there may be noticed one to several angular or concentric folds. In the midst of all these variations the nucleus is uniformly white, solid, devoid of *theques*, but containing the very minute,oblong sporidia, which enclose at their ends two globular, opaque sporules; these sporidia are not more than 1/200 mm. in length.

" A veritable Proteus, this fungus has been the cause of several errors: we find it as No. 321 of our specimens of the *Scler. suec. exs.*, under the name of *Sphaeria Doli-*

olum; one of the samples of No. 1076 of the *Stirpes* of Vosges is still *Phoma Lingam*, under the name *Sphaeria Olerum*; finally, it is probable that the *Sclerotium sphaeriaeforme* Lib. is still *Phoma Lingam* in a state well developed, but without fruit. "

It is seen at once that although this description includes the fungus upon which we are working, yet the terms are so vague that they would include many other species also, and at present this can hardly be taken as the original description of our fungus, and the name *Phoma oleracea* must still stand.

It is very possible that the fungi described by Saccardo (3:135) as varieties of *Phoma oleracea* are not varieties, but belong to the true species *Phoma oleracea*, and that the species *Phoma Napobrassicae* Rostr. listed by Saccardo (11:488), and those given by him (3:153-154) as *Phoma siliquarum* Sacc. & Roum. and *Phoma siliquastrum* Desm. may be also included under the same species. This can only be determined by inoculation experiments and the examination of numerous specimens, and constitutes one of the important phases of the problem still to be worked out.

CULTURAL CHARACTERISTICS OF THE FUNGUS.

Isolation of the Organism.

The fungus is easily isolated from the host by removing a bit of the diseased tissue from the leaf, stem or petiole, disinfecting for 45 seconds in 1:1000 solution of mercuric chloride, rinsing in three changes of sterile water and plating on potato agar or other suitable nutrient agar. In two days mycelium begins to develop from the tissue, and pycnidia formation usually starts by the fourth day.

The fungus has been grown upon a number of different culture media in order to learn its manner of development upon the various substrata. The media used for this purpose, with their methods of preparation, are here given:

Preparation Of Cultural Media.

Plain or beef agar: In 500 cc. of water dissolved 10 grams Witte's peptone, 5 grams sodium chloride, and 3 grams Liebig's Beef Extract; cooked in steamer until dissolved. Cooled to 50° C. and added 500 cc. water in which was dissolved 15 grams agar. Added white of one egg beaten in a little distilled water. Boiled in steamer until a good coagulum was formed. Titrated and found to be +8., Fuller's scale. Filtered through cotton, tubed, and sterilized in autoclave 20 minutes at 10-12 pounds.

Lima bean agar: To 1 liter tepid water added 100 grams ground Lima beans and soaked them for 30 minutes. Strained through cloth and squeezed out all juice possible. Restored to original volume. Added 15 grams agar and cooked in steamer until dissolved. Found by titration to be +6.,Fuller's scale. Tubed and sterilized in autoclave 20 minutes at 5-7 pounds.

Some of this media was filtered through cotton as soon as dissolved, then tubed and sterilized as above.

String bean agar: Cooked 400 grams string beans for 1 hour in steamer in 1 liter of water. Strained through cloth, squeezing out all juice possible. Restored to original volume. Added 15 grams agar, and cooked until thoroughly dissolved. Titrated: +8., Fuller's scale. Tubed and sterilized in autoclave 20 minutes at 5-7 pounds.

Cabbage decoction agar: Took 500 grams of tender inner leaves from head of cabbage, and boiled in steamer about 30 minutes in 1 liter of water. Squeezed through cloth and restored to original volume. Added 15 grams agar. Found by titration to be +33., Fuller's scale; tubed and sterilized in autoclave 20 minutes at 5-7 pounds.

Oatmeal agar: Placed 50 grams Quaker Oats in an Erlenmeyer flask and added 350 cc. water. Cooked 30 minutes by conducting live steam through a tube under the surface of the mixture in the flask. Strained through 12-mesh wire gauze. Added 15 grams agar dissolved in 200 cc. water. Steamed as before for 30 minutes. Added water to 750 cc. Titrated and found to be +2.5, Fuller's scale. Tubed and sterilized 15 minutes at 8-10 pounds.

Some of the agar prepared as above was left at an acidity of +2.5 Fuller's scale, some of it was adjusted to +10. by addition of normal hydrochloric acid, and some was adjusted to -5. by addition of normal sodium hydroxide.

Thaxter's potato hard agar: Peeled and sliced 250 grams of potato. Cooked for 1 hour in steamer in 1 liter of water. Squeezed through cloth and restored to original volume. Added 20 grams glucose and 30 grams agar. Cooked in steamer for about 1 hour. By titration: +7. Fuller's scale. Tubed and sterilized in auto clave 15 minutes at 10 pounds.

Rice agar: Weighed out 75 grams dry rice and cooked for 1 hour in steamer in 1 liter water. Squeezed through cloth, restored to original volume and added 15 grams agar. Cooked until thoroughly dissolved. Titrated: +0.5 Fuller's scale. Tubed and sterilized in autoclave 15 minutes at 15 pounds.

Synthetic culture medium: Dissolved the following ingredients in 1 liter of water:

Dextrose	100.	grams
Peptone	5.	"
Ammonium nitrate, NH_4NO_3	10.	"
Potassium nitrate, KNO_3	5.	"
Magnesium sulphate, $MgSO_4$	2.5	"
Potassium acid phosphate, K_2HPO_4	2.5	"
Calcium chloride, $CaCl_2$	0.1	"
Agar	20.	"

Sterilized in autoclave at 5-7 pounds.

Cooked string bean pods: Placed in the bottom of each test-tube a little absorbent cotton, about 1 cm. deep. Saturated with about 1 cc. distilled water. Upon this placed a piece of string bean pod 2 1/2 inches long. Plugged and sterilized in steamer on three consecutive days.

Cooked cabbage plugs: Cut plugs 1 1/2 inches long and about 1/4 inch square from tender pith and leaves from near central bud of cabbage head. Tubed in same way as string bean pods, with moist cotton in bottom of tube. Sterilized in steamer on three consecutive days.

Raw sterile cabbage plugs: With sterile, flamed knives, under a transfer hood, cut away the outer layers of a cabbage head. In a similar manner cut away another complete layer from the head. Then with sterile knives cut plugs 1 1/2 inches long and 1/4 inch square from the tender central pith. With sterile forceps placed them in tubes which had previously been prepared by fitting with wads of cotton saturated with distilled water, plugging, and sterilizing. The tubes were again plugged, and were later found to be in a sterile condition.

Raw sterile potato plugs: Prepared tubes by placing in the bottom of each a wad of absorbent cotton about 1 cm. in depth. Saturated with about 1 cc. distilled water; plugged and sterilized. Placed in each tube a plug about 2 inches long cut under sterile conditions from the inside of a potato tuber. Replugged.

Corn meal: Placed in a 150 cc. Erlenmeyer flask 5 grams of yellow corn meal. Added 50 cc. water. Plugged and sterilized in autoclave 15 minutes at 15 pounds.

Rice; Placed in a 150 cc. Erlenmeyer flask 8 grams of dry rice and 48 cc. distilled water. Plugged and sterilized in autoclave 15 minutes at 15 pounds.

Growth of the Fungus on the Various Media.

In these experiments three strains of the fungus were used. #86C had been obtained on August 13, 1910, from T. F. Manns of the Ohio Experiment Station, Wooster, Ohio. #119 had been isolated August 29, 1911, at the Wisconsin Experiment Station, by Miss F. M. Bachman from specimens of cabbage brought from Onalaska, Wisconsin; its pathogenicity had later been tested, by inoculation, by Miss Bachmann. #128 was isolated by the writer July 22, 1912, from diseased cabbages from Onalaska.

No constant morphological differences were found between the several strains, and there is no reason to doubt that they belong to the same species. However, some general differences were found in vigor and in tendency to fruit. On all the different media #86C produced the most abundant mycelium, dense, of a grayish white, but showed a tendency to form only a few pycnidia; although the latter were finally produced to some extent in every tube they never spread freely over the surface of the media, and were usually rather scarce and covered by the heavy mycelium. #119 showed the strongest tendency and capacity to fruit, and in all cases produced more pycnidia than either of the other strains; the mycelium of #119, though vigorous, was always less abundant than that of #86C. #128, in

general, was very similar to #119, but slightly less vigorous; a little slower of growth and did not produce pycnidia quite so abundantly, though this character was not very marked.

In the following description of cultural characters only #128 will be followed through the entire series of media, but mention will be made of the other strains if their behavior differed materially from that of #128 except in the general and fairly constant manner described in the preceding paragraph.

Plain agar: Proved a relatively poor medium for the culture of Phoma oleracea. At the end of five days mycelium had spread about 6 mm., and formation of pycnidia had just started. One day later a thin layer of very small brown pycnidia could be distinguished under the mycelium. At the end of one month from the time of inoculation the very scant, white mycelium had not entirely covered the slope, and the small pycnidia were present mostly near the point of inoculation and at the very edges of the mycelium. #86C produced a somewhat heavier mycelium but very few pycnidia.

Lima bean agar: Slight mycelial growth visible when three days old. When five days old a few large pycnidia were present. One day later large pycnidia, first red,

later black, were very abundant near the point of inoculation. They soon spread until they were scattered over nearly the whole slope. Thirty days after inoculation the large pycnidia were present over the whole tube and formed a naked layer or flat, reddish mass near the center, while the mycelium constituted a dense gray felt over the surface.

Lima bean agar, filtered: Growth of all strains upon this medium was a little faster and more vigorous than upon the unfiltered Lima bean agar. Pycnidia formation was also stimulated, even #86C producing numerous large fruiting bodies.

String bean agar: Upon this medium the growth of mycelium was surprising slight, though a few long threads spread rapidly over the surface. By the fourth day pycnidia formation started, and one day later minute pycnidia were visible over the entire surface of the slope. By the next day these pycnidia were large in size and pink in color. At the end of a month the pycnidia were large and reddish, scattered over the entire surface, but the growth of mycelium was still very limited. #86C produced an abundant mycelium, slightly pinkish white, and formed rather numerous large pycnidia scattered over the entire surface.

Cabbage agar: Mycelium rather dense but did not spread fast. Formation of minute pycnidia started in five days over nearly the whole surface. At the end of one month the rather abundant mycelium, slightly grayish white, had covered the slope, and had produced a layer of small black pycnidia. #860 produced few pycnidia.

Oatmeal agar, acidity of +2.5 Fuller's scale: This medium produced a vigorous but curiously irregular, massed, lumpy growth of grayish white mycelium, with black pycnidia in irregular groups from which the spores were often liberated in purplish pink masses. In #119 this production of pycnidia in masses was particularly remarkable.

Oatmeal agar, +10. Fuller's scale: Growth was somewhat slower in starting than upon the preceding medium, and the pycnidia were of a greenish black color; otherwise growth was similar to that of the preceding.

Oatmeal agar, -5. Fuller's scale: Mycelial growth much less than upon the preceding media, and few pycnidia were formed.

Thaxter's potato hard agar: This medium gave rather rapid growth of mycelium; fruiting was begun in four days. Two days later masses of pycnidia had formed near the point of inoculation. Within one month the mycelium had become

dense and grayish white, and large pycnidia were abundant over the whole surface. This is a good medium for the keeping of stock cultures of the fungus.

Rice agar: Within three days a very thin mycelium was spreading rapidly over the slope; very little aerial mycelium was produced at any time. Five days after inoculation a well-defined part of the surface was covered with a rather close layer of uniformly large, greenish-black pycnidia. Within one month small bunches of mycelium had begun to form, and the surface was covered with the large greenish pycnidia, even on strain #86C.

Synthetic medium: Within six days a short, dense mycelium had covered nearly the entire surface, and overgrew a low, solid mass of pycnidia near the point of inoculation. At the end of one month the mycelium was dense but short; in the center were wrinkled pycnidial masses about 1 cm. broad, covered with the short mycelium.

Cooked string bean pods: Slight, downy growth apparent in two days. Development of reddish pycnidia evident on the fourth day. On the sixth day the mycelium was still scant, but lines and masses of large, reddish pycnidia nearly covered the pods, in some places laying open the

surface of the pod in long scars. At the end of one month the pycnidia were more black in color and mycelial growth was beginning to cover the pods.

Raw sterile cabbage plugs: Slight downy growth evident on third day. By fifth day the mycelium had spread about 1 cm. from point of inoculation. By next day it nearly covered the plug, and the tissue was starting to darken; in some cases this discoloration apparently preceded the complete death of the tissues; pycnidia had just started to form a few millimeters from the point of inoculation. Discoloration of the cabbage tissues continued until the whole plug was black. In some cases the fungus mycelium appeared to have penetrated the plug and emerged on the opposite side in about a week. The formation of pycnidia occurred only on dead tissues. One month after inoculation the mycelium was still scant and thin; black pycnidia were abundant near and above the point of inoculation, but not below it. The tissues were shrunken and in some cases cracked, but they were not broken down, and there was no soft rot.

Cooked cabbage plugs: Mycelial growth was very apparent within two days and progressed rapidly, covering about half the plug with a dense white growth within the next three days. Sometimes the mycelium heaped itself into loose,

rounded masses. With #119 the formation of very large red pycnidia was observed on the sixth day; with the other strains it began later, and on most the pycnidia remained covered with the dense, wooly mycelium, exposing themselves only at the top of the plug. This medium gave the most vigorous growth of mycelium of any of the series, but also afforded the formation of the fewest pycnidia. The cabbage tissues finally became intensely black throughout.

Raw sterile potato plugs: Unfortunately there was not sufficient water in the bottom of these tubes to keep the potato plugs moist and to promote a good growth of the fungus. It was at first thought that the fungus in the tubes was dead, but it finally began to show over the surface of the potato in scattered threads, and one month after inoculation the plugs were nearly covered with a very thin, white mycelium, and pycnidia had been formed on the lower ends of the plugs and in the absorbent cotton at their base, where most of the moisture was held.

Corn meal: Slight mycelial growth observed on third day. By sixth day this aerial mycelium had developed very little, but part of the surface was covered with a layer of small greenish pycnidia. These soon spread over the entire surface, and then a superficial mycelium was developed, until one month after inoculation the whole surface

was covered with a mat of grayish or brownish-gray mycelium. A dark green coloration extended about 6 cm. into the medimm.

Rice: A slight downy growth was apparent on the third day. Two days later the spot of rather close white mycelium had spread about 1 cm., and had produced a dense layer of greenish pycnidia. Two days later the dense mycelium had just about covered the surface of the medium. At the end of a month the mycelium had formed a thick, smooth mat, entirely covering the pycnidia, and the whole substratum, which was about 1 cm. deep, was colored an intense black.

In summary of the above results it may be said that the fungus grows least abundantly upon the synthetic medium and the beef agar, on which it produces a scant mycelium and few pycnidia. On all the other media a rather abundant production of both mycelium and fruiting bodies occurs, though in varying degrees. On those media on which the most abundant pycnidia formation takes place, the string bean agar in particular, relatively little mycelium is produced; and on cooked cabbage plugs, for example, where the mycelium is most dense, pycnidia formation is very slow and scanty. On some media the fungus shows a tendency to form solid masses of pycnidia 2 or 3 mm. in depth, rather than to spread over the surface. On string bean agar a layer of reddish pycnidia develops very rapidly over the

entire surface of the slope, but little mycelium is formed; on potato agar, beef agar, Lima bean agar and cooked string bean pods the pycnidia also have a reddish or purplish appearance; on cabbage agar they are almost black, even when first formed; but on the more starchy media, rice agar, rice and corn meal, they are greenish black or almost olive-colored when first formed; on corn meal they turn black when about a week old.

SYMPTOMS AND FIELD RELATIONS OF THE DISEASE.

In the Seed Bed.

The black-leg disease first becomes noticeable in the seed bed when the seedlings have developed three or four leaves, two or three weeks before the time of transplanting. The affected plantlets can often be recognized by the grower by their smaller size and pale color; they do not have a vigorous appearance (Plate 1). If they be pulled from the ground and examined (Plate 2) there will be found on the stem of each near the surface of the ground a smooth, whitish, sunken area; at first this spot is small, but it rapidly enlarges, encircling the stem and extending upward often to the leaves and downward to the roots. The lateral and frequently the tap-roots will be entirely missing. The pycnidia of the fungus (Plate 3) may be seen with the naked eye as minute black dots scat-

tered over the surface of the sunken lesions. It is seldom that Phoma appears on the leaves of plants still in the seed bed. While the disease may be abundant all over the seed bed, it generally occurs in little spots; where several plants grow close together all are frequently diseased, and those for perhaps one foot each way in the row. The writer was not able to determine any difference in the virulence of the attack on distinct varieties.

The pycnidia of the fungus may be seen with the naked eye as minute black dots scattered over the smooth, sunken surfaces on the stem. When the seed bed is located upon ground infected with the black-leg fungus, the development of the disease is so general among the seedlings, without even the slightest trace of insect injury, that it seems quite unlikely that at this stage the fungus is dependent upon insect injury for a means of entrance into the host. It appears quite probable that while the tissues of the cabbage seedlings are young and tender the fungus can force its way through the healthy epidermis of the stem. This idea is somewhat strengthened by the result of an experiment started on August 16th in the pathological garden. Two greenhouse "flats" were filled with uninfected garden soil. The heads of two badly diseased cabbages were cut finely and mixed with the soil in flat No. 1; no infection was placed in the other flat. Eighty healthy

volunteer cabbage seedlings, two inches high, were carefully lifted from the cabbage seed garden and transplanted into the two flats, forty plants in each. They were cared for during the rest of the summer, and by the first of November all but three of the plants in flat No. 1 had either been killed by black-leg or showed signs of being infected, while only one of the plants in flat No. 2 had the disease. Since the flats had been placed side by side in the garden this plant may have been infected by handling. This experiment is not satisfactory, since some wounds were undoubtedly made in the seedlings at the time of transplanting, though considerable care was used. But the wounds must necessarily have been slight, not like insect injuries, and it seems altogether that infection occurred through the uninjured epidermis. Insect injury would, of course, by weakening the plant and giving a place of easy access to the fungus, increase the proportion of infection and loss.

It is a question whether the fungus can thus force its way independently into the tissues of the older plants after they have passed the tender seedling stage and before reaching the dormant condition of maturity. Harter states (1912:24) that " leaf infections also occur at the margins, generally at the ends of the larger veins. " The writer made a number of inoculations, by several different

methods, upon plants in the pathological garden at the experiment station. The plants were all making vigorous growth and were just starting the formation of heads. A water suspension was used of spores from a pure culture of *Phoma oleracea* grown upon Thaxter's potato hard agar.

In cases where the spore suspension was sprayed upon the stems and leaves of the plants, but where no wounds were made, no infection was secured, but this may have been because the plants were not covered well enough after the inoculations, to maintain a moist atmosphere. Where wounds were made through the epidermis of stems or lower leaves with the sterile needle or scalpel, and the spore suspension sprayed on or a drop of the liquid placed over the wound, infection was obtained in every case, without regard to whether the plants were covered or not. However, when the spore suspension was introduced into wounds made in the inner, most rapidly growing leaves, a callous ring was soon formed, the wounds healed and no infection occurred. The tissues were sufficiently vigorous to resist and overgrow the fungus and prevent its entrance or spread. The formation of the lesions of the disease upon these large, thrifty plants was very slow in all cases; small blackened areas gradually developed on the inoculated stems and leaves; pycnidia finally made their appearance in most cases; and three months after the inoculations were made

all those plants which had had the fungus introduced into their stems were nearly or quite dead. Nearly all of them had formed heads, but the disease had in most cases spread up into the base of the head and onto the petioles of the lower leaves. The stems appeared as if gnawed by insects, only woody shreds being left in some cases.

Inoculations were also made in the greenhouse, from spore suspensions from pure cultures of *Phoma oleracea*. In these experiments a drop of the suspension was placed on the desired spot and a prick made with a sterile needle through the drop of liquid and through the epidermis of the cabbage tissue. Infection was secured from all inoculations except one made on an old woody stem, which failed to contract the disease. About two weeks after inoculating, small blackened areas could be discerned spreading from the wounds made in leaves or petioles. At the end of another week pycnidia had appeared in one or two cases. Thirty days from the time of inoculation pycnidia were present on most of the lesions.¶Two pots were taken, containing three cabbage plants each; the plants were small, each having four or five leaves. Inoculations were made in the stems of two plants in each pot, in the axil of the lower leaf in each case. The third plant in each pot was left for a control. Inoculations were made in the same manner as on the older plants mentioned above. Ten days later it was

evident from the discoloration of the stems that the disease had gained a foothold in the tissues. Pycnidia appeared in from eighteen days to three weeks from the time of inoculation, and three weeks later the lesions were 25-40 mm. long, depressed, and covered with pycnidia. No sign of the disease appeared in either of the two control plants.

It is not the custom among farmers to carefully look over their seedlings at the time of transplanting, and when diseased plants, such as are shown in Plates 1 and 2, are placed in the field it is obvious that the trouble will be merely transferred from one location to another, and be given even more favorable conditions for its development, for the plants are more or less weakened by their removal and transplanting. The effect of this manner of spread of the disease is very conspicuous in the field within a month from the time of transplanting; this was the case in 1912 during the first part of July. By that time the disease had developed far enough to produce unmistakable symptoms, chiefly of wilting, as shown in Plate 4. A purplish color of affected plants was also prominent, and was a certain symptom of the disease even before wilting took place. The occurrence of the sick plants consecutively in single rows was very striking (Plate 5). Obviously, in each of these spots a handful or group of diseased seedlings had been planted, one after the other,

as the machine moved down the row. If the seedlings at the time of transplanting had been inspected and the diseased ones destroyed this loss would have been largely avoided.

The weather was dry and warm at this time, in early July, and all sick plants had drooped and wilted for lack of water. They may revive during the cool, moist night, but soon wilt again in the morning, and do not usually survive long. An early and late stage of the wilt are shown in Plate 6. The cause of the symptom is lack of water in the plant, occasioned by the loss of the lateral and often of the tap-roots. Stages in the development of this condition are shown in Plate 7. The disease does not follow the vascular system to any great extent, but works through the stem in any direction it chooses without regard to the character of the intervening tissues (Plate 8). In time it cuts off the roots and spreads up into the lower part of the head, sometimes cutting off the petioles of the lower leaves.

If the weather is favorable for the growth of the plant, i. e., moist and cool, adventitious roots are usually produced above the diseased spot, as shown in Plate 9. If these roots develop vigorously the plant may not be killed immediately, but may live through the entire season; seldom, however, does such a plant produce a marketable head.

Plants injured and killed by Phoma are usually left

in the field, and serve as a ready source of infection for the healthy plants around them. Pycnidia are produced in large numbers on their stems and even on their lower leaves. The spores mature and may be carried to new plants by wind, water, or mechanical means. Insects become abundant, and it is clear that a diseased plant, like that shown in Plate 10, is an ideal source of infection.

Within two months from the time the plants are placed in the field this second means of infection begins to produce results. At this time the diseased plants do not appear conspicuously in rows, but rather in broad spots around the plants originally infected, (Plate 11). From this time on, the spread of the disease is general throughout the field, giving the appearance shown in Plate 12. These later infections occur upon the upper leaves, around insect injuries or at the margins quite as often as they do upon the stem. The spores may be carried by the wind, the cultivator, insects or other means, but it appears probable that, except in the cases of marginal infection mentioned by Harter (1912:24), entrance into the tissues is afforded to the fungus only through wounds. The greater number of these wounds are made by insects (Plates 10 and 18 in particular), so it is at this point and in this way that these pests cause the greatest damage. The rapidity of development of the disease and the loss caused by it are

somewhat dependent upon weather conditions, as affecting both the fungus and the vigor and resistance of the host, due, for example, to the formation of adventitious roots.

Plants infected late in the season after they have formed heads do not usually exhibit such marked symptoms of wilting as plants infected earlier. This may be partly because there is more water or succulent material stored in the head, but is also due to the fact that infection often occurs on the leaves instead of on the stem, and these leaves will be killed before the fungus has had time to spread and cut off the vascular system of the stem. Examples of this are shown in Plate 13, and less strikingly in Plate 14; in the latter case, however, the head is somewhat wilted, for the disease has spread into the stem.

It occasionally occurs that the disease does not spread to any large extent in the field, even though many infected seedlings have been transplanted. In that case one sees in the field at harvest time conditions like that shown in Plate 15, where the originally infected plants, as shown by their position in the row, became diseased, but the trouble was not carried to the other plants, or if so was not carried in time to cause damage. The spot shown in Plate 15 is located on low, rich soil, planted to cabbages for the first time; the field was well cultivated throughout the season and the plants were

very vigorous. The cabbage worm was present and active, as shown by the photograph, but did not cause so much injury as in most of the fields in the vicinity. This picture should be contrasted with Plates 16 and 17, pictures of a field where cabbage had been planted during 1911, where the ground was not so rich and had been poorly cultivated, and where theinjury caused by both the cabbage worm and the cabbage maggot was very considerable. Here the writer found black-leg in abundance, as well as black rot. No heads were harvested from this field in the fall of 1912.

Plates 18 and 19 show two fields where the soil is fertile and well tilled, but where there had been cabbages grown in 1911. The damage was caused by infection in both seed bed and field. On the extreme left, in Plate 19, is a type of cabbage differing from the others in the field in the number and color of the leaves and the shape of the head. This type was not so generally attacked by the disease as the other. The seed from which the plants were raised was supposed to be all of the same variety, the " All Season ", so no definite information as to varietal differences in susceptibility could be secured. It should be said that black rot also caused considerable damage in this field.

Plates 20 and 21 are photographs taken in a field at harvest time, 1912, where there were not enough market-

able heads to send to the kraut factory; the loss was practically total. Cabbage had been grown on the land previously, but not during 1911. The soil was light and sandy. The plants in this field had been grown in a seed bed which had been found by the writer to be generally infected with Phoma, and seedlings from which are shown in Plates 1 and 3. Insects were present in the field, but not in unusually great numbers, and the apparent damage caused by them was slight. No plants affected with the black rot could be found in this field. It is the opinion of the writer that infection of nearly all the plants occurred in the seed bed or by spores transferred in the process of transplanting. At the time the photographs were taken, counts were made of the healthy, sick, and dead plants in six full rows across this field. The results follow:

	Number of plants.	Per Cent.
Apparently healthy	5	0.33
Diseased, but formed heads (few marketable)	296	19.42
Entirely destroyed	1223	80.25
Total	1524	100.00

It was thought that, since infection was practically universal in the field, the five apparently unaffected plants must show some individual resistance to the disease, and that this resistance might be transmitted to their offspring. Accordingly they, with seven others found in

the field, were marked with stakes, were left in the field until in danger of being frozen, and were then pulled from the ground and shipped to the experiment station at Madison to be stored during the winter and again planted in the spring for the purpose of raising seed from them. It was hoped that some resistance to the disease might thus be found and perpetuated, as suggested by Ritzema Bos (1906:274), but unfortunately the storage room was kept at too high a temperature and the plants did not live until spring. It is expected that during the present spring and summer (1913) several of the better kraut varieties of cabbage will be grown on this infected field, in hopes of finding some varieties in a measure resistant to the disease.

In order to learn more about the desirable varieties of cabbage and the possibilities of growing seed in Wisconsin, the writer asked Mr. George B. Smith, of the firm of Smith Bros. of Green Bay, Wisconsin, for information on this subject. Mr Smith is a skillful gardener and careful observer, with many years of practice in the growing of seeds, truck crops, and cabbages for both market and kraut purposes. He willingly gave the results of his experience, and, since his observations are of especial value, a part of his letter of February 15, 1913, is here quoted:

" I think we have experimented with nearly all var-

ieties of cabbage that have been grown in this country. . . . . We will not consider anything smaller than the Jersey Wakefield. . . . .I will consider it [the question] first in the light of a full line [of cabbage].

" For the first early, use Early Jersey Wakefield. It is very hardy and vigorous in growth. Solid head and large enough for first early.

" Charleston Wakefield is quite similar to the first named, but considerably larger and two weeks later.

" Copenhagen is of the same season as Charleston Wakefield, but more round in shape of head, and of a light green color, about the same size as Charleston Wakefield.

" Henderson's Summer is at the head of the list for a good all round flat cabbage, not too flat, and plenty large enough for retail market, two weeks later than Charleston Wakefield.

" Henderson's Succession is a large flat cabbage, but not too flat to weigh well. It is an immense cropper, and sure header, three weeks later than Summer.

" All of the foregoing are very hardy, and under any sort of conditions that any cabbage will head, they will.

" I presume you know that some varieties of cabbage require a heavy loam in order to get a fair development of head, but any of the above will do well on a loam of light

weight, and of course will do well on a heavy loam, or a fluffy soil.

" The Succession is the cabbage that we ALWAYS plant when we plant only for kraut, and when we have contracted with growers to furnish cabbage it has been the variety we have used.

" The All Seasons was introduced about twenty five years ago. It has not proved as easy a header as the Succession; it requires more time and richer soil, and lighter soil. A large tonnage per acre can be grown of it if the conditions are right, but they must be better than are required for Succession, or there will be a good many heads that will make a very inferior development and the final result is not so satisfactory.

" All of the foregoing varieties are sold by first class seedsmen.

" I think there is no possible question of the success of growing cabbage seed in either large or small quantities in this locality, if a person understands how to grow the seed. Of course the cabbage must be late ripened stock, and handled right, just the same as anything else.

" I am intimately acquainted with a retired gardener who lives in the outskirts of Green Bay, who raised Holland Cabbage for many years, and it was a well-known fact that he raised the finest Holland Cabbage that was grown in this

locality.

" There is another gardener living one half mile from our garden who has raised his own seed for years, and it has been a great success.

" In both of these cases the cabbage remained true to shape, time of growth, weight, color, and possessed the quality of not bursting open on account of getting over-ripe, to a wonderful degree.

" Now I am not telling you something that someone has told me; I have seen and handled this cabbage.

" About disease, I am absolutely convinced that a large part of the disease in cabbage is in the seed when it comes into the cabbage grower's hands. We have been quite successful in selecting a variety of Holland that suited our conditions in this locality and was reasonably free from disease, when other dealers were having much trouble.

" I went into a garden belonging to one of our neighbors, and saw a bed of cabbage, one half of which was very fine indeed, and the other half almost ruined by disease. I asked, 'John, what makes this cabbage look this way?' He answerer, 'I wanted to see if your seed was better than Mr. ______'s, and I planted it all on the same day, and manured the land all the same way, set it out at the same

time, cultivated it the same way (apparently his work had been perfect), and you see how it is. The cabbage from your seed is all good, and that from Mr. _____ is all sick.'

" Now it is my belief that any of the varieties of cabbage mentioned can be continuously propagated in this locality. "

At present a large part of the seed planted in Wisconsin is imported, principally from Holland. However, a large amount of seed is grown on Long Island, in New York, and a relatively small quantity in the state of Washington, near Puget Sound. Although the natural home of the cabbage or its predecessors was on strongly calcareous soil, near the shore of the ocean, in a relatively cool and moist climate, yet the present status of our knowledge seems to indicate that the plant will complete its life history and produce seed satisfactorily, perhaps quite as well, under the climatic and soil conditions of Wisconsin, particularly along the shore of Lake Michigan. Considering, then, the undoubted benefits to be derived from home seed production, in the wayof selection and improvement of varieties and strains, as well as the prevention of entrance of the disease on the seed, and the development of resistance to specific maladies, an attempt should be made to encourage the growing of seed in this state by seed firms, and better still, if possible, by individual farmers for their own use.

Spread of Disease by Sale of Infected Seedlings.

One of the most common means of spreading the disease in a locality is by the sale of seedlings from an infected seed bed. In a village or city it is usual for one or a few gardeners to raise a large number of seedlings and distribute them to neighbors and customers. One case of this was found near Madison. It is also practiced in regions where cabbagesare grown more extensively. For example, on July 10, 1912, there were sold to a neighbor two wagonloads of seedlings from the bed shown in Plate 1, and which supplied the fields shown on Plates 5, 20, and 21. The neighbor who bought these seedlings planted them in one side of his large field; the rest of the field was planted with seedlings from his own, slightly infected seed bed. By harvest time the division between the two parts of the field was very marked. The crop grown from the seedlings from the badly infected seed bed was a total loss; the damage in the rest of the field was not over 25 per cent. This emphasizes the necessity for keeping the seed bed on clean soil and free from infection.

Overwintering of the Fungus.

The fungus undoubtedly lives over winter in cabbage refuse, either in the stumps and worthless heads left on the field or in leaves and waste from the kitchen, stable,

storehouse or factory, depending upon the use to which the cabbages are put. If a mature head becomes infected it will carry the trouble to the factory. or, if shipped to a city market, it may spread the disease into a very distant territory. Whether the fungus forms a perfect stage and lives over the winter in that condition also, is not known.

Relation of Soil to Occurrence of the Disease.

The writer was not able to determine any connection between kind of soil and prevalence or virulence of the disease, so long as the soil was carefully and thoroughly tilled and was not too poor in the elements of plant food to support a vigorous growth of the plants. Bad attacks of the malady have been seen on low, black "muck", on very light sandy soil, on a rich friable loam, and on a heavy clay loam, so the disease appears to be somewhat indifferent as to the quality of the soil upon which the cabbages are grown.

Plate 22 shows a field of vigorous, healthy cabbages, giving promise of a profitable yield at the end of the season. The contrast between this and the two preceding photographs indicates the results of careful and thorough cultural and sanitary methods.

CONTROL AND PREVENTIVE MEASURES.

No experiments have been carried on by the writer in regard to specific measures for controlling black-leg, but field observations have shown the practicability and necessity of certain practices to insure freedom from the disease in hitherto uninfected localities, and to get rid of the trouble where it already exists. Most of the methods are necessarily preventive in character.

The wide distribution of the disease over the state, even in districts where cabbage growing is a new industry, would seem to indicate that the trouble is carried by the seed. Since there is no reason for thinking that the fungus penetrates to the inside of the seed ~~coat~~ it is probable that the spores are carried on the surface of the seed coat, and in this case it should be possible to kill these spores by thorough disinfection with formaldehyde. Manns (1911 : 259)

advises soaking the seed twenty minutes in a solution of one part formaldehyde in 320 parts of water. Harter (1912: 10) recommends soaking fifteen minutes in a solution of the strength of 1:224. He adds:

" The seed should be left in the solution about fifteen minutes, dipped in pure water to wash off the formaldehyde, and then spread out to dry. Even greater strengths of formaldehyde can be used without injury to the seed if care is exercised to wash and dry thoroughly. "

A most important practice for the control of blackleg as well as for other reasons, is the rotation of crops. This is particularly essential with regard to the seed bed, which should never be located on land where cabbage, cauliflower or other related crop has been previously grown, or where water will drain from an old cabbage or cauliflower field. For fertilization of the seed beds or for heating hotbeds no manure should be used which contains cabbage refuse in any form.

Harter (1912:10) also suggests sterilizing the seed bed by any one of the following four methods recommended by W. W. Gilbert (1909:34) for sterilization of tobacco seed beds: (1) steam sterilization by means of drain tile laid in the bottom of the beds, through which steam is passed; (2) sterilization by means of an inverted pan

under which steam is admitted; (3) sterilization by drenching the soil with a formalin solution, 1 to 100 or 1 to 200, three-fourths of a gallon per square foot of area, several days before the bed is to be used; or (4) treating soil with Bordeaux mixture, as recommended by Manns (1911:288); this method is to treat the seed bed, immediately after planting, with Bordeaux mixture (4:4:50 formula) at the rate of one gallon per 10 square feet, by means of a sprinkling pot; repeat the application two weeks before and again just preceding transplanting into the field. Manns says, " These treatments will keep the disease down in the seedbed, and prevent distribution of the disease during transplanting. "

The first two methods of sterilization named are not usually within the ability of the ordinary farmer, for they require the use of a steam pressure boiler and other special apparatus. If care is taken to plant disinfected seed on clean soil it is not likely that the disease will be obtained in the seed bed. However, these precautionary measures, especially the treatment with Bordeaux mixture, are not likely to do any harm and may well be practiced.

All seedlings should be carefully looked over at the time of transplanting, and all diseased, weak or unhealthy plants discarded. If eggs of the cabbage fly are found the

seedlings should be cleaned in some way, as by washing.

Seedlings should not be transplanted into fields where cabbages or cauliflower have been grown during the preceding three or four years at least, and preferably longer. All the land should be kept free from cruciferous weeds, such as black mustard. Cattle should not be pastured on old cabbage land and then allowed to run over other fields.

Very much more attention should be given by the growers to control of insects, especially the cabbage maggot and the cabbage fly. This comes more properly within the province of entomology, but is so closely related to the question of disease control that it should be mentioned. Most growers seem indifferent to the ravages of insects so long as the cabbages survive the attack, and do not consider the partial loss that they suffer. It is probable that this question will in a large measure be solved by the practice of proper sanitary and cultural methods, such as rotation of crops, removal of weeds, and immediate destruction of all cabbage refuse.

This collection and destruction of all sick plants and cabbage refuse is one of the very important means of controlling the disease on farms and in localities where it is already present. It should also be observed at

storage houses and kraut factories. If possible, all cabbage land should be plowed deeply immediately after harvest, and left in the rough condition over winter. This is especially desirable for controlling the cabbage maggot, the insect being killed in the plowed ground during the winter. Another possible and more thorough method of removing cabbage stumps after the harvest is by pasturing the field to sheep; they will clean up every vestige of refuse, and will thus destroy the fungus present in the old plants. However, care should be taken not to let the sheep run from the cabbage field onto uninfected areas, or the disease might very easily be carried on their hoofs and thoroughly introduced into the clean soil.

Another and most general measure for control or prevention is the practice of good methods of culture and crop sanitation, to give the cabbage plants the most favorable conditions possible for their development, to give them a strong power of resistance to the disease. The soil of the seed bed should be well prepared and the field should be kept in good tilth, in the best physical condition, and entirely free from weeds.

The last possibility is the trial and selection of those desirable market varieties which are least susceptible to the disease, or the production and attempt to fix, by selection and breeding, resistant strains of any

desirable type. This offers a hopeful line of profitable experimentation, and should be followed thoroughly. Since the cabbage is biennial and does not produce seed until the second year of growth, it takes some years to obtain any definite results from such work, but from the success that has been obtained in this direction with other plants, and even in cabbages in developing resistance to another disease, one can at least hope that equally good results may be secured in obtaining cabbage plants resistant to the black-leg.

CONCLUSION.

It was stated in the introduction that this paper is a report of progress of the work upon this disease. As a matter of fact, many important problems have been merely opened up or brought to light and then left unanswered. Some of the more fundamental questions thus left open for further work and future settlement may be mentioned:

Determination of mode of infection of young and old plants, and relation of insects to spread of the disease.

Determination of the spread of the disease upon the seed; whether the spores can live thus for long periods of time; whether such spores can cause infection in the young plants; and corroboration of the harmlessness and efficiency of the common means of seed disinfection.

Determination of the condition in which the fungus

lives in the soil. The possibility of a perfect stage should, of course, not be overlooked.

Study of cytology of the fungus and of the disease.

Determination by inoculation experiments of the susceptibility of other cruciferous plants, both cultivated varieties and weeds; also of the susceptibility of the members of other families, possibly including some of the so-called varieties of the fungus under the true species.

Production, by trial, selection and breeding, of varieties or strains of cabbage and cauliflower quite or more nearly resistant to the black-leg disease.

Summary.

The work covered in the present paper may be briefly summarized as follows:

Commercial cabbage culture is an important industry in Wisconsin, and has in some sections of the state been endangered by the appearance and spread of certain diseases, one of which is called the black-leg.

This disease was first described by Prillieux and Delacroix in France in 1890, and again mentioned by them in 1897 and 1909. Its occurrence in Australia was noted by McAlpine in 1901. In 1906 and 1907, respectively, Ritzema Bos and Quanjer published reports upon the disease in Holland. In 1911 Manns, of Ohio, and in 1912 Harter, of the

United States Department of Agriculture, treated the disease in popular bulletins. It has in recent years been reported in Ohio, Michigan, Iowa, Virginia, New York, Louisiana, Oregon and Wisconsin.

The disease has been known in Wisconsin since 1911. It is most injurious near Onalaska, but is known to occur in seven widely separated counties and is probably thoroughly scattered throughout the state.

The disease is caused by a fungus, Phoma oleracea Sacc.

The fungus lives over the winter in the soil or cabbage refuse, and may infect the young plants in the seed bed, probably without previous insect injury. Lesions of the disease appear upon stems of the seedlings, near the surface of the ground.

The plants are not usually killed in the seed bed, but are often transplanted into the field, where they soon wilt and die. They are left in the field and serve as sources of infection for the plants around them. The spores may be spread by wind, water, insects, animals, by the cultivator, or other mechanical means. Total loss of crop may occur.

The development of the disease is somewhat dependent upon the weather and upon the vigor of the host plants, but seems to bear no relation to the kind of soil.

Some varieties or types appear to be more resistant than others to the disease. This should be investigated with a view to establishing quite resistant varieties or strains of cabbage.

Measures to be recommended for the prevention of the disease consist in: seed disinfection; possible sterilization of the seed bed, and its location upon uninfected soil; rotation of crops; inspection of seedlings at time of transplanting; control of insect pests; collection and immediate destruction of all diseased plants and cabbage refuse; fall plowing; proper methods of culture and sanitation; and development of marketable varieties or strains of cabbage resistant to attacks of this disease.

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NOTE.

Prints and negatives of the photographs shown on the succeeding pages may be found in the files of the Wisconsin Experiment Station. Plates 1, 4, 5, 13, 14, 15, 16 and 17 are photographs taken by the writer. All pictures were made near Onalaska, Wisconsin, during 1911 and 1912, or (Plates 2, 3 and 9) show plants brought from Onalaska.

PLATE 1.

Black-leg on stems of young cabbage plants in seed bed at Onalaska, Wisconsin. July 11, 1912.

PLATE 2.

Cabbage seedlings attacked by black-leg. Healthy plant at left.

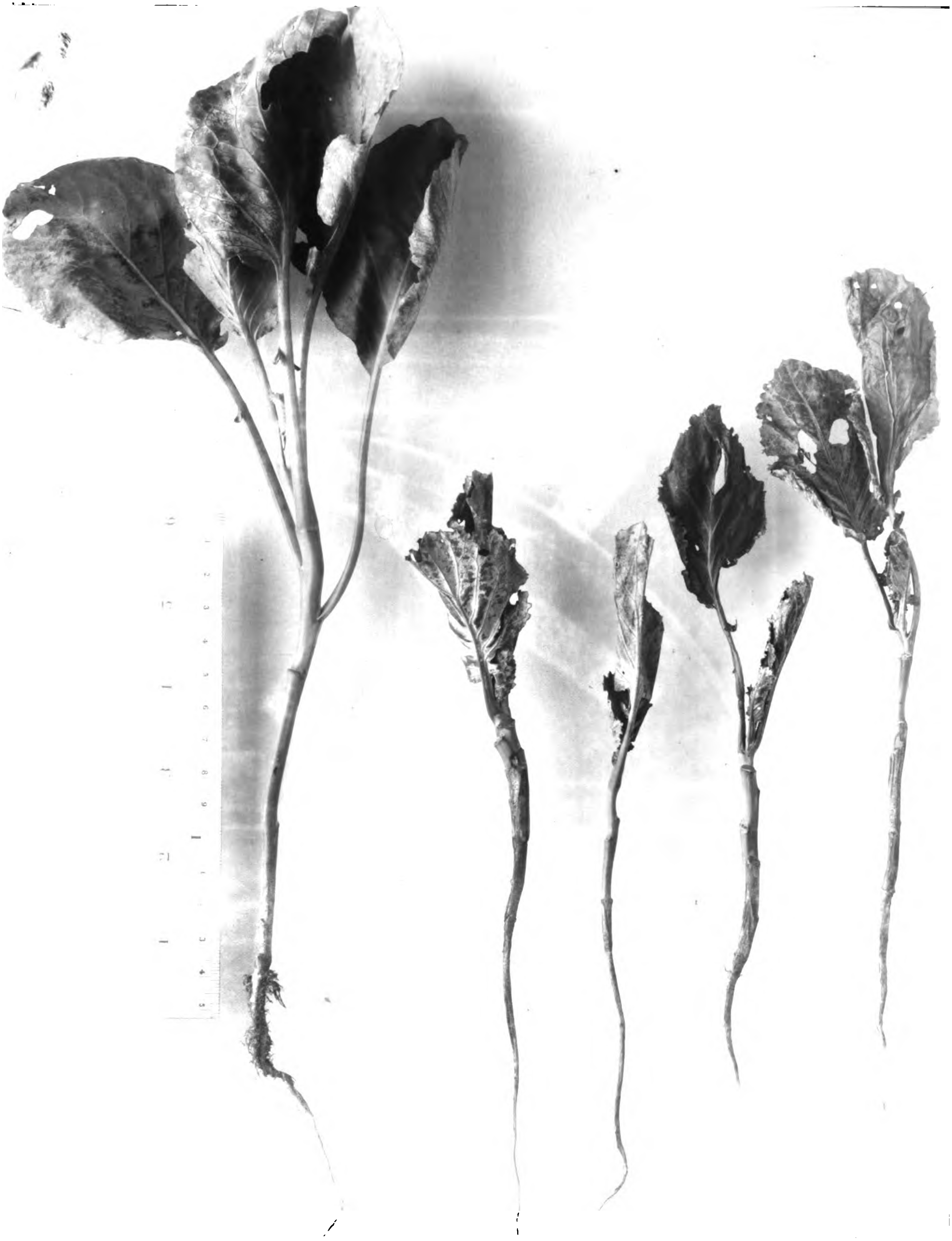

PLATE 3.

Stems of cabbage seedlings attacked by black-leg. Magnified about two diameters. Note pycnidia of the fungus. July 11, 1912.

PLATE 4.

Healthy and diseased cabbage plants in field about one month after transplanting. Shows characteristic wilting. July 11, 1912.

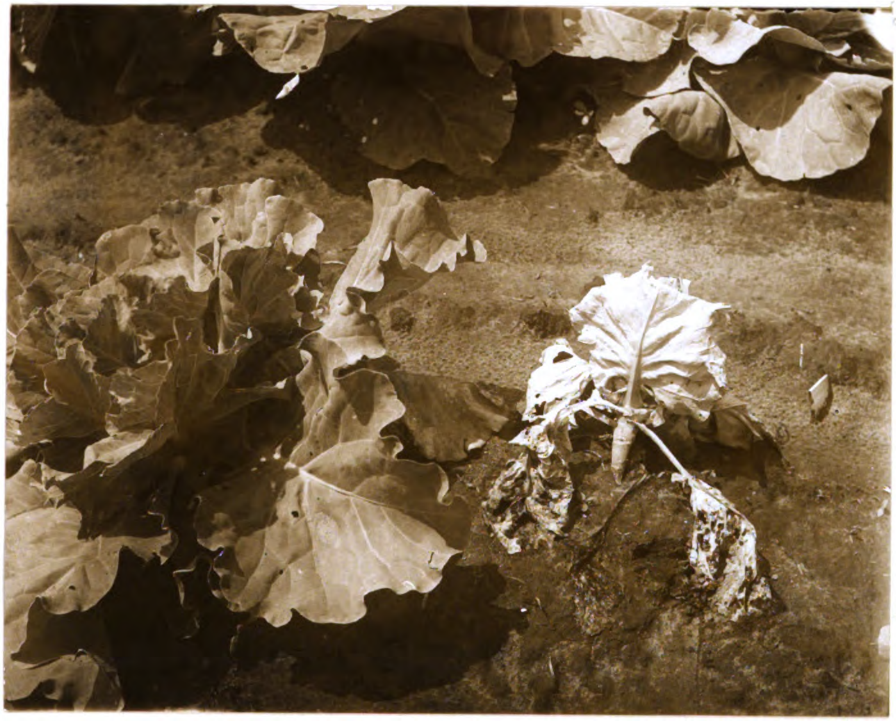

PLATE 5.

Infected cabbage field about one month after transplanting. Note row of wilted plants in center of field; effect of transplanting diseased seedlings. July 11, 1912.

PLATE 6.

Cabbage plants affected with black-leg. Early stage of wilting shown at right, later stage at left. August 10, 1911.

PLATE 7.

Black-leg of cabbage plants. Shows progressive stages in destruction of root system and consequent wilting and death of plants. July, 1911.

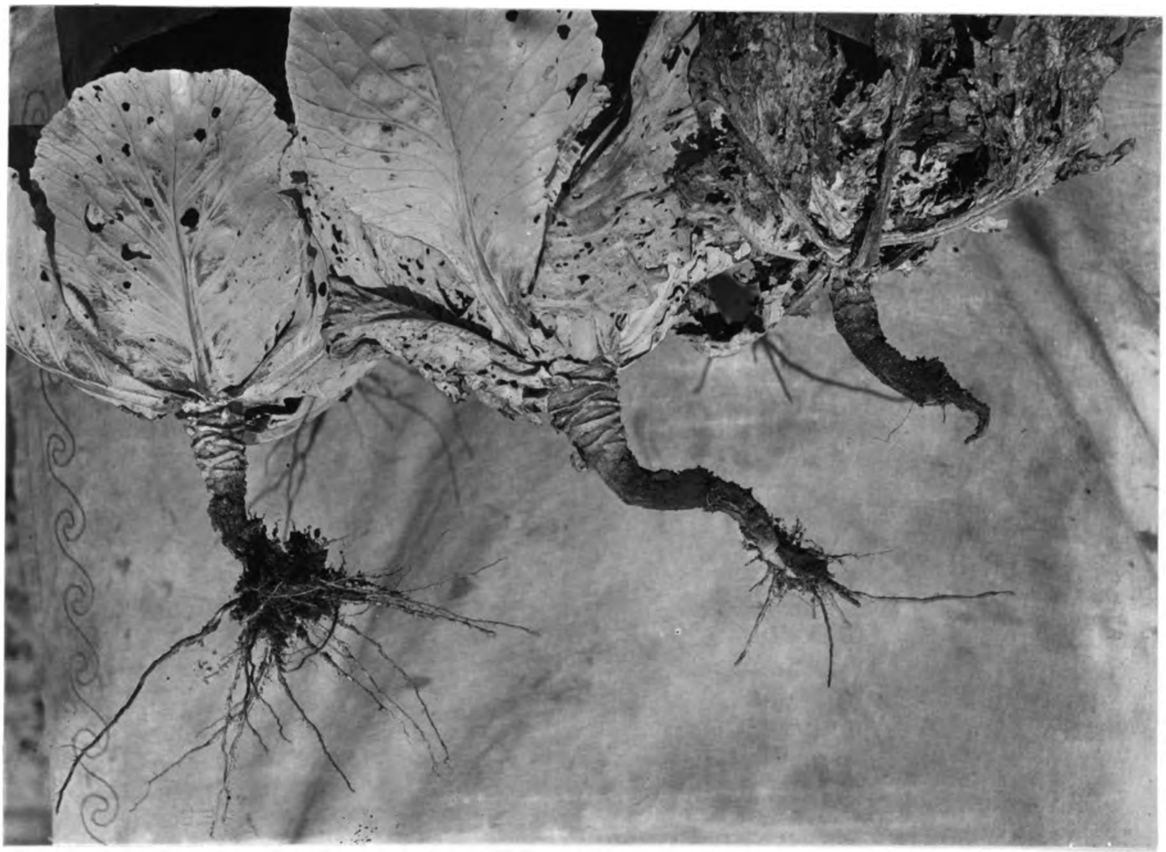

PLATE 8.

Cross section of cabbage plant affected with black-leg. Shows discoloration, due to fungus invasion, extending irregularly through stem and into lower leaves, not following vascular system. 1911.

PLATE 9.

Black-leg of cabbage. Shows destruction of roots and later formation of adventitious roots above the point of attack. July 8. 1912.

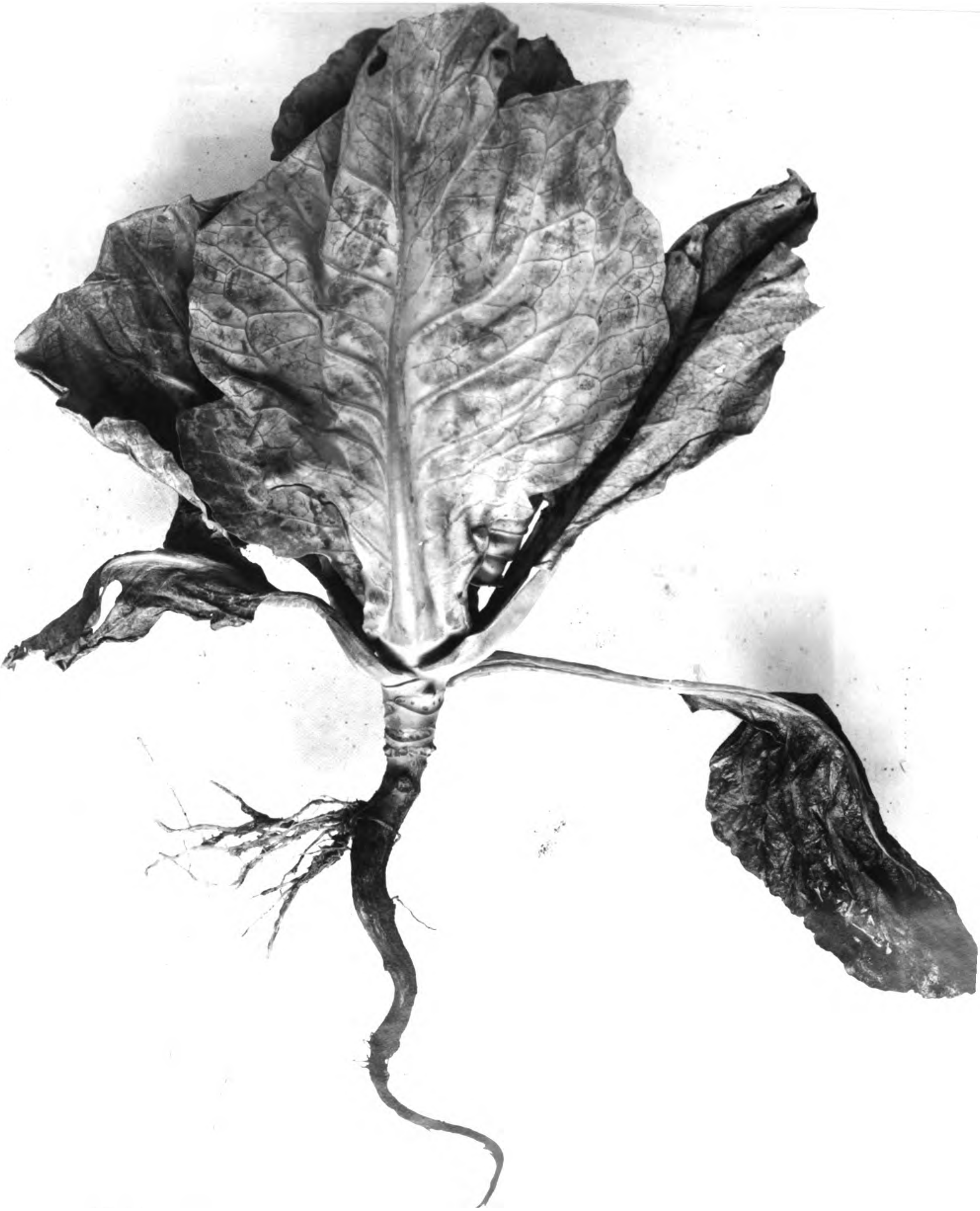

PLATE 10.

Cabbage plant wilted by blackleg. Note damage caused by cabbage worms. An excellent source of infection for surrounding plants. 1911.

PLATE 11.

General wilting of cabbage plants due to black-leg disease. 1911.

PLATE 12.

General wilting and death of cabbage plants, due to black-leg. 1911.

PLATE 13.

Cabbage plants attacked by black-leg in late summer, after formation of heads. September 3, 1912.

PLATE 14.

Plants attacked by black-leg in late summer. September 3, 1912.

PLATE 15.

Black-leg of cabbages in late summer. Still shows effect of transplanting of infected seedlings. Unusual condition, where the disease did not spread rapidly in the field. September 3, 1912.

PLATE 16.

Field of badly diseased cabbages. Attacked by black-leg, black rot and insects, including cabbage maggot. Crop a failure. September 3, 1912.

PLATE 17.

Another portion of the badly diseased field shown in Plate 16. September 3, 1912.

PLATE 18.

Field of cabbages damaged by black-leg and some black rot. Result of repeated cropping to cabbage. September 30, 1912.

PLATE 19.

Field of cabbages attacked by black-leg and some black rot. Result of repeated cropping to cabbage. Previous treatment of entire field was uniform. On extreme left note the variety apparently little injured by either disease, showing some resistant power. September 30, 1912.

PLATE 20.

Field of cabbages nearly destroyed by blackleg. Note a few apparently resistant individuals. September 30, 1912.

PLATE 21.

Field of cabbages nearly destroyed by blackleg. Note a few apparently resistant individuals. September 30, 1912. (Same field as in Plate 20).

PLATE 22.

Field of healthy cabbages. Onalaska, 1911.

Approved by L R Jones per A.G.J.

Professor of Plant Pathology.

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